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PLATE II

The Manor House of Woolsthorpe, Lincolnshire, in which Newton was born, December 25, 1642.

(From *The Times Literary Supplement*)

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NEWTON AFTER THREE CENTURIES

THE SEARCH FOR UNIVERSAL LAWS: MODERN SCIENCE AND THE "PRINCIPIA"*

(With Plate II)

THE puny child who was prematurely and posthumously born on Christmas Day, 1642, at the manor of Woolsthorpe in Lincolnshire, lived to a more than usually ripe old age. When he died on March 20, 1727, Sir Isaac Newton had not only defied the laws of Nature; he had understood them to an extent greater than any of his predecessors or contemporaries. The mere catalogue of his discoveries takes away the breath; and a perusal of his "Philosophiae Naturalis Principia Mathematica" fills the mind with awe. Yet it was not as the supreme discoverer of all time that Newton appeared to himself. In order to comprehend the secrets of Nature, it is necessary "to sit down before the facts like a little child"; and along with a marked irritability in controversy and a just appreciation of his own gifts in comparison with his rivals', Newton displayed a rare humility before the Book of Nature and the Author of that Book.

> I do not know what I may appear to the world: but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, while the great ocean of truth lay undiscovered before me.

And in another place, "If I have seen farther than other men, it is because I have stood on the shoulders of giants." These familiar sentences, which so deeply touch our hearts to-day, are the key to Newton's greatness. He unravelled so much of the Book because he

*From *The Times Literary Supplement*, December 26, 1942.

came to it with an open mind. The composite nature of light, the forces that keep the moon and the planets in their orbits, the daily round of the tides, the paths of the comets, the binomial theorem and the method of fluxions—these unfolded themselves to him because he was ready to learn. Yet, though he lived so long, they were all discovered within a short space of time. He was not an infant prodigy, nor even in his early years at Cambridge was his ability pre-eminent; and after middle age he made no great discoveries. Several of his chief accomplishments can be pinned to a few years; all were made within a quarter of a century. But they were such that within his lifetime he had become a national institution; and without yielding to flattery the Dean and Chapter of Westminster could permit to be inscribed on his tomb, *Sibi gratulentur mortales, tale tantumque extitisse, humani generis decus.*

So much has been heard lately of the "overthrow" of Newtonian physics that it is well to remind ourselves of the eternal greatness of Newton; though, in truth, considered simply as a scientific theory apart from its philosophical assumptions, Newtonian physics has not been overthrown so much as subsumed into a more embracing scheme. Within the limits of experimental accuracy open until quite a recent date, Newtonian physics remains valid; if it is no more, it is a first approximation. What is it,then, that makes Newton a model for men of science in all ages?

Pre-eminently, he saw that the object of science is to deduce the general from the particular. It is the business of science to find the simplest set of hypotheses which will explain all the known phenomena. Such a definition combines Plato's instruction to the astronomers of the Academy "to save the appearances" with "Occam's razor," that "entities are not to be multiplied beyond necessity." This latter is, indeed, placed by Newton as the first of the "Regulae philosophandi": "for Nature is simple and does not indulge in superfluous causes." It is this search for simple general laws or principles that distinguishes science from the mere collection of facts. To give an elementary instance from one of Newton's own discoveries, it is not science to work out that

$$(1+x)^2 = 1+2x+x^2 \text{ and } (1+x)^3 = 1+3x+3x^2+x^3,$$

but it is science to show that both the right-hand expressions are particular forms of a general formula for $(1 + x)^n$.

Gravitation

Over all his predecessors, and over most of his successors, Newton was the supreme exponent of general laws. Galileo had removed certain misconceptions about motion which had prevailed since the days of Aristotle; Kepler had discovered three laws governing planetary motion; but Newton found three laws of the utmost generality governing the motion of *all* material bodies. "Every body perseveres in its state of rest or of uniform motion in a straight line except in so far as it is compelled to change its state by impressed forces." Such a definition was possible only when it was grasped that rest and uniform motion in a straight line are analogous states; and it needed a genius to grasp that fact. Newton's achievement can be appreciated if we ask why it was that Galileo, who was on the verge of the discovery of these laws—who knew, in fact, their content—never succeeded in formulating them.

The same point is enforced by the familiar story of the way Newton's mind leapt from the falling of an apple to the univeral law of gravitation, a story which may well be true even though it was told by Voltaire. Many people had seen apples fall; but no one previously had realized that the same cause which made the apple fall might keep the moon in her orbit; or, at least, no one previously had worked out a law which would simultaneously account for the falling of apples and lunar motion. The law, when enunciated, was sublime in its generality: "*Every* particle in the universe attracts *every* other particle" and so on. In the literal sense, it means that we cannot move a flower "without troubling of a star."

How can we be sure that such general laws will "save" all the phenomena? Only by testing them. There is nothing in the nature of things to compel us to say, "This must be the law of gravitation." The history of science is a road strewn with discarded hypotheses. It is a process of trial and error, in which hypotheses must be adjusted to the phenomena, not the phenomena to the hypotheses. Newton himself showed that his hypothesis explained a wide range of facts; it was the task of the next century, and more especially of Laplace in

his "Mécanique Céleste," to show that it covered all the known celestial phenomena.

Theory and Experiment

This leads to the second of Newton's claims to be a supreme example of the scientific spirit. In no other person has the combination of theory and experiment been so complete and so harmonious. Perhaps Archimedes in ancient times might have rivalled him in this respect; but beyond the story of the crown and the bath, and some ingenious engines of war, nothing is certainly known of Archimedes' experimental life. Faraday was as great an experimental philosopher as Newton; Clerk Maxwell was as great a mathematical physicist; but Newton combined the experimental genius of Faraday with the mathematical acumen of Maxwell. It was as though in our own day he had united the virtues of Rutherford and Dirac. He had no elaborate apparatus or team of experimenters, but relied on his own efforts, supplemented by the kettles of a colleague in a neighbouring set of rooms.

The third of Newton's claims to scientific genius is that his laws expressed a quantitative and measurable relationship between phenomena. They are, in a word, mathematical; and if anyone is responsible for making physics and astronomy "the sciences of pointer-readings" it is Newton. The first law of motion is followed by the second, relating the rate of change of a body's motion to the impressed force; and the law of gravity not only postulates that every particle of matter attracts every other particle, but provides a formula for calculating the magnitude of the attraction.

There is no room for dispute about pointer-readings; and Newton removed science from the field of barren disputation and set it on the sure path of measurement. His fourth claim to scientific genius is linked with the quantitative nature of his laws and may best be expressed in his own words, *Hypotheses non fingo*—where hypothesis no longer means a working generalization but an assumed physical entity whose existence cannot be tested. ("Whatsoever is not deduced from the phenomena is called *hypothesis*; and hypotheses, whether metaphysical, or physical, or of occult qualities, or mechanical, have no place in *experimental philosophy*.") It is true that Newton

did not always live up to his own ideal, and from time to time he toyed with ethers and other "hypotheses" for filling empty space; in the second edition of the "Principia" he fell back on the notion of an "occult cause" for gravitation; but the prevailing note in his work is the statement of quantitative relationships between phenomena and the implied banishment of all "occult causes." Thus the law of gravitation is to be understood as a statement of measureable relationships among systems of bodies, and leaves as an entirely open question *why* bodies move towards one another. It is true that the law uses the concepts of attraction and force, but only as a piece of shorthand; without the use of such words the law would become intolerably prolix. But it expresses no opinion on the nature or cause of gravitation; it was left for such men as Le Sage to essay that task.

After Newton

In these four respects Newton's work has set a model for all subsequent investigators; and it is in the light of these permanent features that the "overthrow" of Newtonian mechanics should be studied. While the quantitative differences between Newtonian mechanics and modern science are small, and can be detected only at the microscopic and macroscopic ends of the scale, there is a wholly different philosophy underlying Newton's work from that which underlies the General Theory of Relativity and Quantum Mechanics. The basic assumptions of these theories are irreconcilable with the basic assumptions of Newton. The chief of Newton's philosophical assumptions concerns the nature of space and time; and although he owed much to Gassendi, it was his "Principia" which riveted the concepts of absolute space and time on the world for 250 years. "Absolute space," he lays down in a famous scholium, "in its own nature, without regard to anything external, remains always similar and immovable"; and "all things are placed in space as regards order of situation." Space is thus the theatre in which the cosmic drama is played. It would exist even though there were no players on the stage or spectators in the auditorium. It is homogeneous and devoid of all properties except extension. The whole of space, and of each point in it, exists throughout an infinite succession of instants of time; and the existence

of such infinite succession of instants means that the notion of *simultaneity* throughout the whole of space is valid.

In a fascinating presidential address delivered before the Royal Society of Edinburgh recently Professor Whittaker shows that Newton elevated space and time to a pre-eminence unknown among Aristotle and the School-men. With them *where* and *when* were only two among the ten predicaments of Being. He also shows how the philosophical assumptions of Relativity and Quantum Mechanics are in some ways a return to scholastic and Aristotelian ways of thought. When an electron, for example, leaves one orbit for another it is not to be thought of as traversing an infinitude of points between the two orbits. Indeed, the concept of the identity of a single electron persisting unchanged in its passage through space has been abandoned, and we are left with something like the universal quality of *electron-hood* manifesting itself in individual electrons at different points.

Unchallenged

This is indeed an "overthrow" of Newtonian conceptions not to be minimized. But it would be unfair, in acknowledging this philosophical revolution, not to pay tribute to the permanence of Newton's methods. To give one final instance: many physicists in recent years have sought a "unified field theory" which would exhibit gravitation and electricity as different expressions of one fact. If this attempt should be crowned with success it would be a generalization entirely in keeping with Newton's own discovery of a single law covering all gravitational phenomena; and it would be the perfect complement to it.

Despite the achievements of the subsequent years Newton's place at the head of the roll of science has not been challenged. Is it not, then, a national disgrace that no complete and satisfactory edition of his works has been published? For most of them we still must have recourse to Samuel Horsley's edition published in 1779-1785. Even the "Principia" is not very easy to obtain; and it is no credit to Newton's countrymen that this immortal work had to be published at Halley's expense. Admittedly war-time conditions make such a tercentenary project impossible; but when peace returns the Royal Society could not better honour its greatest fellow than by producing a worthy edition of his works, as the Royal Institution has done for Faraday.

GALILEO, NEWTON, HALLEY: THE MEN THEMSELVES*

By M. A. EVERSHED

IT IS a great honour to be allowed to introduce to you the three great astronomers whose centenaries we are celebrating today. Galileo died and Newton was born 300 years ago, in 1642; Halley was a younger contemporary of Newton, and died 200 years ago, in 1742. Before we hear about their work, I shall try to describe, very briefly, what the men themselves were like.

GALILEO was rather tall, broad-shouldered and sturdily built; fair, with rosy cheeks and blue eyes, reddish hair and beard. He was intensely alive, active and eager; rather quick-tempered but easily recovering his good humour; with a great capacity for joy and also for sorrow. He was a Florentine, and so, of course, he loved beautiful things. Indeed he was an artist born. As a boy he painted, played the lute exquisitely, and delighted in making models and toys. When he was older he invented and made scientific instruments of many kinds, and was a brilliant lecturer and writer. But a love of nature and study of her laws was his passion. At school and college in Pisa, and as professor there—on a most meagre salary—he found that all the teaching was based on authority, chiefly Aristotle's: young Galileo demanded proofs, and showed by his experiments that the professors were wrong; and as he was skilful in argument and had a gift for sarcasm, he made some enemies.

But he always made friends, too, and one of these secured for him a professorship in mathematics and astronomy at Padua. Here he quickly won his way to success, happiness and fame. His lecture-hall was so thronged that sometimes he had to speak in the open air. When he made his first telescope his name rang through Europe. He made and sent away many others, and with each copy of his *Sidereal*

*At the meeting of the Royal Astronomical Society in London on October 9, 1942, addresses on the scientific achievements of Galileo, Newton, and Halley were delivered by Prof. H. Dingle, Prof. H. C. Plummer and Dr. H. Spencer Jones (Astronomer Royal), respectively. Preceding them brief biographical sketches of these men were given by Mrs. John Evershed, which we take the liberty of reprinting from *The Observatory* for December 1942.—*Editor.*

Messenger—a beautiful piece of writing, very simple, but throbbing with excitement and joy over his wonderful discoveries. He called the four satellites of Jupiter the "Medicean Planets," after Cosmo dei Medici and his three brothers; and a Frenchman wrote begging him to discover another heavenly body "as soon as possible" and call it Henry after the King of France!

Then came the crowning happiness, for Cosmo dei Medici made him Chief Philosopher and Mathematician at his court, so he could return to his beloved Florence, and live in the beautiful hills to the south, overlooking the beautiful city. Near him, in a convent, lived his daughter, and her touching little notes and letters to him reveal a very tender side of Galileo's character. He visited her often, sent her wine of his own growing, and did little commissions for her in the Florentine shops. She washed and mended for him those wide white collars which he wears in all his portraits.

After many happy years, shadows fell on his path. We all know the tragic story of his summons to Rome, when old and ill, and how he was compelled to recant and abjure on his knees the Copernican heresy of the Earth's movement round the Sun—as the Inquisition judged it to be—though he still cherished it in his heart and mind. He was not imprisoned, and before long he was allowed to return to Florence, to be interned in his own house in Arcetri.

One blow followed another. His daughter died. His sight failed and he gradually became quite blind. Yet his brave spirit triumphed: it was during these last years that he composed his most valuable work, and just before he died he dictated a design of a pendulum clock. He was visited by many friends and admirers, including our own Milton; and the young Viviani, "Galileo's last disciple," stayed with him to the end. So closed at last those eyes which Castelli, his "first disciple," and life-long friend, called "the noblest eyes that Nature ever made, which saw more than the eyes of all who are gone, and opened the eyes of all who are to come."

Isaac Newton was born after his father's death, and was such a tiny feeble baby that he was not expected to live. Yet he grew up to develop not only one of the mightiest intellects we have ever known, but also a fine physique with almost flawless health. He lived

to be 84 and never needed to wear spectacles; all his senses were keen; he had capable clever hands; and he used to say that nothing ever gave him a headache except the Moon!

Like the boy Galileo, the boy Newton was very fond of making things that worked—water-clocks, windmills, sundials. But, unlike Galileo, he was reserved and silent; and he had a wonderful power of concentration which explains his well-known fits of absent-mindedness. It was when riding home from school one day that he dismounted to lead his horse up a hill, and found when he reached the top that he still had the reins in his hands but the horse was gone! Later on, he became so absorbed in working out problems that he would sleep only a few hours each night, and when he was reminded that a meal was waiting for him, would say: "Oh, haven't I had it?" Once he said in reply to a flattering question: "If I do differ from other men, it is that I *can pay attention* to a subject."

But when, by this "paying attention" to a problem, he had found the solution, he had not the least desire to proclaim or share his discovery. It was in his early twenties, at home at Woolsthorpe Manor with his mother for two quiet years, when the plague had driven him away from Cambridge, that he made all his great discoveries—or at least their beginnings. It was then that he saw the falling apple which gave him the key to the greatest of them, as he described later. Yet it was not till 20 years after that Halley persuaded him, with difficulty, to complete and publish it; and when the *Principia* was written: "It's your book now," he said to Halley, and called it "Halley's book."

This, strange to say, was the end of his great creative period, although he was only 44. Diffierent reasons have been suggested for the break he now made in his life. One reason was surely the death of his mother and the impression this made upon him. He loved her, and when at this time she fell ill he went to her and nursed her devotedly to the end. Thenceforth he lived no longer in Cambridge but in London, and a pretty niece came and kept house for him, entertaining all the distinguished people who wanted to know the famous Mr. Newton. He became Master of the Mint, was knighted by Queen Anne, elected President of the Royal Society and presided at all their meetings—though he once fell asleep in the chair! He

seems to have liked the feel of human life all around him, and to meet men like Wren and Locke. Yet he remained intensely reserved, and though he was always kind and generous, people found him difficult to understand, and he did not understand them.

He wrote books on history and chronology, and found an absorbing interest in the prophecies of Daniel and the Apocalypse.

How true of him are Wordsworth's unforgettable lines:

> . . . . . A mind for ever
> Voyaging strange seas of Thought, alone.

EDMUND HALLEY is of a different type again. His was a sunny, open nature, as simple as Newton's was mysterious; his life held no great tragedy, no early struggle, like Galileo's. He was sociable and friendly, sometimes shocking serious people by his jokes and his "colourful language," but winning most hearts by his frankness and sympathy. He put tremendous energy and enthusiasm into his varied work for science, and had a generous admiration for the work of others. He not only persuaded Newton to write his *Principia*, but also paid all expenses of publication and saw it through the press.

He married when only 26 "an agreeable young Gentlewoman," says a contemporary Memoir, "a Person of real merit," "with whom he lived very happyly and in great agreement, upwards of 55 years."

Unlike Galileo and Newton, each of whom knew his own country only, and not a large part of that, Halley travelled widely by land and sea. He decided at 16 to be an astronomer, and left college before taking a degree in his eager desire to sail to St. Helena and catalogue the southern stars. He wrote home in disappointment about the continual rain there, but characteristically did not forget to add a word of praise for his assistant: "Mr. Clark is a person wonderfully assistant to me, in whose company all the good fortune I have had this voyage consisteth, to me all other things having been cross."

Soon after, he visited Hevelius in Dantzig, Cassini in Paris, and other distinguished men of science in France and Italy, leaving everywhere, it was said, "a memory of his amiable disposition and rare intelligence."

Afterwards he sailed the seas, making pioneer observations in meteorology and magnetism. For he was a pioneer in many directions, and it was typical of him that he never grudged doing long and

arduous work which would benefit those who should follow him. This is true of his 20 years work as Astronomer Royal, and especially on the orbit of "Halley's Comet," whose return he predicted but could never hope to see.

He died at the age of 85, after a full, happy and useful life.

THE ATMOSPHERE OF JUPITER*

By Ruth J. Northcott

THE planet Jupiter has been known since prehistoric times. The early astronomers recorded the position of the planet as it moved among the stars and determined its period. With the invention of the telescope more information was gained about this great planet. In 1630 belts parallel to the equator were detected. William Herschel, with his genius as a telescope maker and as an observer, found in 1793 that the belts showed a great variety of detail and colour. He suggested that, owing to their rapid changes, the belts must really be clouds in the planet's atmosphere. The face of the planet has been under constant scrutiny ever since that time, and the motions and changes of the markings on the planet are now systematically observed by the "Jupiter Section" of the British Astronomical Association.

A number of fairly well-defined zones are more or less permanent. Most of the markings are short-lived; their shapes show continual change. There is no doubt that they are atmospheric phenomena. Sometimes small well-defined bright and dark spots are observed in the belts which may last for several months and these may be used to determine the period of rotation of the planet. Since these clouds are drifting in the various currents, the period varies from one zone to another just as in the case of the sun. At the poles the period is about 9h 55m 40s and at the equator it is about 9h 50m 25s, but there is no progressive regularity as in the case of the sun.

In contrast with the short-lived markings which may last only a few weeks, the Great Red Spot is a semi-permanent feature. It was first observed in 1878 as an elliptical brick-red spot some 30,000 miles long. The records show that it was present as early as 1831, and may even be identical with a marking observed by Hooke in 1664. The spot is still observable, varying in colour and character, but it has never been as conspicuous as during the first few years after it was discovered. Its period of rotation varies so that it drifts about considerably, and is therefore a floating disturbance, and not part of the solid surface as was once thought.

*A portion of a paper read before the Toronto Centre of the R.C.A.C., November 24, 1942.

Another remarkable marking is known as the South Tropical Disturbance which was first seen in 1901. This is a dark region, some 45,000 miles long, in the belt just south of the red spot. The rotation of the disturbance is a little faster than the red spot so that it overtakes the spot at intervals of two years or more. When the disturbance is overtaking the spot it tends to drag the spot along with it for several thousand miles, the spot then drifting back to its previous position.

The belts are rich in colour. Red, brown and orange predominate but olive-green and bluish patches have also been seen. The colouration is variable, but the two hemispheres usually vary so that when the belts in one hemisphere are very red those in the other are colourless or slightly bluish. The atmosphere of Jupiter is very complex.

The rapid changes in the appearance of the clouds of Jupiter and the richness in their colour led astronomers in the middle eighteen-hundreds to the supposition that the planet must be almost red hot, but not sufficiently hot to be self-luminous. This idea was generally accepted until recently. Actual measures of the temperature of the planet were first made by Coblentz in 1914 and found to be about $-110°$ C. Menzel in 1923 still believed that this was higher than could be explained by solar heat alone. However, further observations by Coblentz and Lampland in 1924 were reduced by Menzel in 1926; the temperature was found to be nearer $-140°$ C. and this lower value was believed to show little evidence of internal heat. Further work was done by Lampland and Adel in 1941 and it is now established that most of the radiation that reaches us from Jupiter is reflected sunlight. The temperature of $-140°$ C. is in close agreement with that expected for a planet at the distance of Jupiter from the sun if the planet were warmed by the radiation from the sun alone. There can therefore be little heat coming from the interior of the planet.

What is the constitution of the clouds in Jupiter's atmosphere? Obviously they cannot be water vapour. The instrument used for the analysis of light is the spectroscope. However, in the case of the planets the spectroscope gives less information than in the case of the hot incandescent stars. This of course is because of the position of the observer and not due to any limitation of the spectroscope. The observations must be made through the great ocean of gases in the

earth's atmosphere; these gases absorb so powerfully in the ultra-violet that except for a small part near the visible region the ultra-violet is entirely cut off. There are also heavy absorption bands in the infra-red. Therefore there is a relatively narrow part of the spectrum available for observation.

Huggins in 1864, in the early days of spectroscopy, discovered visually a strong absorption band in the orange and several weaker ones in the green region of Jupiter's spectrum. The application of photography by Slipher and others led to the discovery of many additional absorptions.

These strong absorption bands had never been observed in the laboratory and until a few years ago their origin remained unknown. In 1932 Wildt drew attention to the agreement in position of six lines, which Slipher had observed in the spectrum of Jupiter, with lines in the spectrum of ammonia, which he himself had predicted from theoretical considerations. He also suggested that some of the bands might be due to methane. This was definitely confirmed by Dunham in 1933 and 1934, who used the 100-inch telescope to get greater resolution of the bands into their component parts. The absorption spectrum of ammonia was determined by passing light through 40 metres of ammonia at atmospheric pressure. This resulted in a complete coincidence between the laboratory spectrum and certain bands in Jupiter's spectrum. Dunham estimated that the amount of ammonia in the atmosphere of Jupiter is equivalent to a layer at least 10 metres thick at normal temperature and pressure. In 1935 Adel and Slipher found that a 45-metre path of methane at 40 atmospheres pressure gave a spectrum a little more intense than that from Jupiter. Therefore the presence of methane and ammonia has been conclusively established. The characteristics of many abundant gases, such as hydrogen, nitrogen, helium, and neon, cannot be observed in planetary atmospheres since they are in the inaccessible part of the spectrum. The whole of the observed absorption bands are accounted for by ammonia and methane.

The knowledge gained by means of the spectroscope deals only with the outermost envelope of the planet. To learn what is underneath, old astronomical data must be combined with new information from the physical laboratories. Jupiter has a density a third greater than water, whereas the earth has a density over five times that of

water. From the flattening at the poles it can be deduced that in Jupiter the central condensation is very great. To account for the low density and the great flattening at the poles, Moulton, nearly 40 years ago, suggested that Jupiter contained great quantities of hydrogen, though the cores might well be rock and iron. The discovery of hydrogen compounds in the atmosphere confirms this view.

It must not be forgotten that the force of gravity at the surface of the planet is considerable. A simple calculation shows that even a few hundred miles below the surface the pressure must be so great as to reduce ordinary gases to about the density they would have when liquefied. In the interior the pressure exceeds any which can ever be studied in the laboratory.

It is possible to work out a model of the planet composed of three layers of material of given density. This was first done by Jeffreys in 1924. He assumed a core of rock, an intermediate layer of ice and an outer atmosphere of compressed hydrogen. Wildt has gone into the subject in great detail and has been publishing papers on the subject since 1934. He estimated that, due to compression, the density of the rock would be increased to 6.0, that of the ice to 1.5 and that of the hydrogen to 0.35. Using these densities he calculated that Jupiter has a metallic rocky core of radius 22,000 miles, surrounded by a layer of ice 16,000 miles thick, and an outer layer of compressed hydrogen 6,000 miles thick. He estimated the pressure at a depth of some 600 miles in the atmosphere to be 50,000 of our atmospheres, which is the greatest pressure studied accurately in the laboratory. At the base of the atmosphere the pressure would be 940,000 of our atmospheres, while at the bottom of the ice it would be more nearly 12,000,000 of our atmospheres. Since the pressure at the bottom of the planet's atmosphere is great enough to solidify even the permanent gases the use of the term "atmosphere" is somewhat misleading. It would be better to call it the outer layer of low density.

Ice is very complicated in structure, there being some seven different kinds, so that the pressures that have been calculated are very uncertain. Wildt concluded that as the planet cooled in its early development the water vapour probably froze to a solid before it could condense to a liquid, passing directly from the superheated fluid to the solid state. The temperature of the layer of ice can hardly be estimated; it depends, among other things, on the amount of radioactive material in the core.

Wildt estimated the mean density of the outer layer to be about 0.78 which excludes most of the possible constituents; all known gases in the solid or liquid states have densities greater than this, with the exception of hydrogen and helium. For example, frozen oxygen has a density of 1.45, nitrogen 1.02, ammonia 0.82. It therefore seems probable that the outer layer of Jupiter must contain large quantities of free hydrogen and helium. This is in accordance with expectation, since the sun and the stars are composed predominately of hydrogen to an amount of about one third part by weight. The next elements in order of abundance are helium, oxygen, carbon and nitrogen. A massive planet such as Jupiter would retain its light constituents, so that large amounts of hydrogen and helium should be expected to be found in its atmosphere at the present time. The presence of these elements cannot be detected with the spectroscope because of the absorption bands due to the earth's atmosphere.

Astronomers feel that their ideas of the broad outlines of the composition and state of the atmosphere are satisfactory but there are many details yet to be explained: the cause of the numerous belts on Jupiter, each with its own definite period of rotation; the nature of the belts and of the dark and bright markings; the nature of the Great Red Spot and the South Tropical Disturbance, and of the numerous colours on the planet.

Wildt suggested that the colours of the belts may be due to the formation of small quantities of iridescent compounds involving sodium. Sodium is known to be present in small quantities in interstellar space, and it is conceivable that Jupiter may have swept up some of it into its outer atmosphere as it moved through space with the sun. Wildt also suggested that the Red Spot may be a vast solid body floating in an ocean of permanent gases, something like an iceberg floating in the ocean. It may be solid hydrogen. Another suggestion is that the Great Red Spot may be caused by volcanic action, and the colours caused by contaminations erupted from Jupiter's deep interior. These are merely suggestions. It remains for the future to answer these many questions with certainty.

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SETTING UP AND ADJUSTING THE EQUATORIAL REFLECTING TELESCOPE

By H. Boyd Brydon

"Perfection is made up of trifles
but perfection is no trifle."

AMONG the methods of setting up and adjusting the equatorial telescope are some especially suited to the circumstances in which the everyday amateur astronomer finds himself. Several were described in a series of articles on Telescope Mountings which appeared in this Journal a number of years ago.[1] As these have been long out of print it is believed that a selection of well tried, simple methods will prove useful, particularly those which enable much of the work to be done in daylight.

Further, it is hoped to avoid certain difficulties which may arise from the manner of wording instructions. For example: while the direction to "pass the telescope to the other side of the pier" can be followed literally in the case of a "German" mounting, in which the telescope is carried on one end of the declination axis, it applies only in principle when the telescope is mounted in the middle of a divided declination axis, as in a yoke or a fork mounting. Again, an adequate driving clock may be specified, whereas the principle of the instruction can be used with equal success without one. Other instances will be recalled.

The degree of adjustment needed depends upon how and where the telescope is to be used. It may have no local habitation but be set up wherever opportunity offers. It may be portable, that is, be used regularly in a prepared position in the open air, but be stored indoors; or it may have a permanent mounting either out of doors or in an observatory. The methods given here are adequate for placing the instrument accurately in such a permanent position. From them the reader can select those which best suit his conditions. However, even in the case of the temporary or one-night stand some adjustment is desirable. The several parts should be in true alignment among

[1]Telescope Mountings for Amateur Builders; this Journal, vols. 30, 31. See particularly vol. 31, p. 156 ff, 1937.

themselves and the pointers of the hour and declination circles and the inclination of the polar axis be substantially correct.

When the telescope is portable, as defined above, the complete programme of adjustment should be carried through, for, by preparing the site as will be described and with the requisite care when levelling the mounting, once the telescope has been correctly placed it can be returned to that position nearly as accurately as if it were permanently established.

There has been added as an appendix the method of converting standard or mean time into sidereal time and the reverse operation. These must be known accurately for making certain adjustments and are continually needed in regular observational work. It is believed that the discussion there given will prevent the confusion which not unnaturally can arise from the apparently contradictory ways in which the necessary data are expressed in various astronomical text-books.

One further preliminary remark: As these instructions are for the inexperienced it may be pointed out that the accurate adjustment of a telescope cannot be accomplished in a few minutes. The beginner in mirror making is warned, or learns by hard labour, to finish his fine grinding before starting to polish. So must he be cautioned to complete each step in the adjustment of his telescope before beginning the next. Care and patience are the tools needed and the reward lasts. The satisfaction of being able to set one's circles to the declination and hour angle of an invisible close circumpolar star and to see it at or near the centre of the field when one looks into the eyepiece, instead of having to fish around for it, is well worth the diligence that correct adjustment demands.

"An equatorial telescope that is in proper adjustment has its polar axis parallel to the earth's axis, its declination axis at right angles to its polar axis and the optical axis of the telescope at right angles to the declination axis. Its circles are so placed that when the optical axis is directed to the intersection of the meridian and the equator, the declination circle will read exactly 0° plus a small quantity due to refraction, and the hour circle will read XXIV or XII, depending upon whether the telescope is east or west of the pier."[2]

[2]On the Adjustment of Equatorial Telescopes; Sir Howard Grubb. This JOURNAL, vol. 15, p. 368, 1921; vol. 16, p. 15, 1922.

If these conditions be fulfilled it is not essential that the optical axis shall coincide with the axis of the telescope tube except when, for easier posture while observing, the upper part or head of the tube carrying the secondary mirror, the eyepiece and the finder, is rotatable upon the lower part. None the less, accurate adjustment of all parts of the instrument among themselves increases its usefulness and insures its performance being equal to its optical quality. In the case of a Newtonian reflector then, there is added to the above conditions that "the optical axis coincides with the mechanical axes of the telescope and eyepiece tubes which intersect at right angles.[3]

Indeed, if these further conditions be not fulfilled, some adjustments are rendered difficult and others impossible.

The programme of adjustment thus falls into three parts: First, of the parts of the telescope among themselves; second, of the telescope to its mounting; third, of the telescope and its mounting to the celestial sphere.

I

Before the optical axis can be brought into coincidence with the mechanical axes of the telescope these must be defined and correctly adjusted.

To define the axis of the telescope tube. The best way to do this is by the standard "tight wire" method. Between stout wooden supports placed across the ends of the tube stretch tightly a fine (say No. 24 B.W.G.) steel or hard brass wire. If an end of the wire be secured to an eyebolt passing through one of the supports the wire can be tightened without twisting by turning a nut on the outside of the support. Move the supports until by feeling with a pin gauge[4] between the wall of the tube and the wire at both ends, the wire is set accurately in the axis of the tube where it is to remain until the next operation is completed.

For shorter tubes and for small tubes such as the focussing tube the following plan is better. In one end of the tube fit a ring having two fine wires crossing its centre at right angles; in the other end fit

[3]This requires that when the secondary is a prism its angles, within negligible error, are 90° and 45°.

[4]A pin gauge is a stick of wood with a stout pin driven into each end. It is adjusted to length by altering the projection of the pins.

a disc having a clean hole ⅛-in. in diameter drilled exactly in its centre. The ring and the disc are each to be rotatable when in place in the tube. If now on sighting through the hole in the disc the line of sight (as defined by the intersection of the wires appearing in the centre of the hole) remains on a fixed mark although the ring or the disc or the tube itself be rotated, each sight must be in the centre of the tube and the line of sight through them therefore defines its axis.

This method is particularly useful when the head of the tube is rotatable, for the axis of rotation of the head must coincide with the optical axis of the main mirror which therefore must coincide with the axis of the telescope tube.

Having defined the axis of the head, the centre of the mirror end of the tube is to be defined by crosswires, the mirror being removed. The axes of the two tubes are in alignment when, as observed through the hole in the disc, the intersections of the two sets of wires are seen to coincide for all positions of the head. If they do not, the planes of the abutting tube ends are not at right angles to the axes of the respective parts of the tube and must be made so, otherwise the necessary adjustments cannot be completed successfully.

To define the axis of the eyepiece tube. Fit the focussing tube with a temporary tube some 6 to 8 inches long. Prepare it with crossed wire and orifice sights as described and find the axis of the tube by rotating the sights. Instead of a temporary tube the eyepiece drawtube of the telescope can be used, an eyepiece without the lenses serving as the disc sight. The eyecap aperture should be small for this purpose.

To adjust the intersection of the axes of the telescope and eyepiece tubes. With the prepared tube in place in the focussing tube, disc sight outside, adjust the fitting carrying the focussing tube until the line of sight intersects the tight wire marking the axis of the main tube. Mark the point of intersection on a target of white card fastened to the tight wire or other convenient way. Rotate the fitting through 180°, secure it in place and again sight the tight wire. If the two points of sight do not coincide the fitting must be reseated until they do. The axes are then at right angles to one another. Finally, rotate the tube containing the sights until one of the wires is parallel to the axis of the main tube, and mark the position to insure its correct

replacement if accidentally displaced. The tight wire may now be removed from the main tube.

To prepare the optical parts for alignment. Secondary Mirror. Define the centre of the secondary mirror by crosswires in its major and minor axes. Set it in place facing the focussing tube and adjust it until on looking through the disc sight its wires coincide with the wires in the temporary or draw tube.

Main Mirror. To check the position of the main mirror, prepare a stiff white cardboard disc of equal diameter and having a central hole of rather more than half that diameter. Fasten two fine wires or black threads to the edge of the disc and crossing its exact centre at right angles to one another. Set the disc so prepared over the mirror and secure the mirror carefully in the centre of its support. Bolt the support in place on the tube.

Now on looking through the hole in the disc or eyecap in the drawtube, there will be seen in the main mirror a reflection of the secondary mirror and its crosswires. If the wires stretched across the cardboard disc appear as extensions of those on the secondary or can be made to do so simply by rotating the disc on the mirror and at the same time both of these sets of wires coincide with the crosswires in the drawtube, both mirrors are correctly placed. If, as is more likely, the reflection of the secondary is displaced toward one side of the main mirror, the main mirror is tilted. It is too close to the secondary on the side where its reflection is seen. To correct, the main mirror must be squared on by careful manipulation of the push-and-pull screws of the support or, if without these screws, by inserting suitable liners until coincidence is attained.

Final proof of the accuracy of the work is given by the image of a star as seen with a high-power eyepiece. Except for atmospheric disturbance the image and its diffraction rings must be circular, both in and out of focus. Any "flare" or extension of the sharply focussed image indicates that the main mirror must be moved away from the secondary on the side on which the flare occurs.[5]

[5]An excellent discussion on the appearance of the magnified image and on the care and testing of the objectives of refractors will be found in Dr. Louis Bell's "The Telescope," Chap. 19. Also in the booklet published by T. Cooke and Sons, of York, England, "On the adjustment and testing of Telescope Objectives" on which much of Dr. Bell's discussion is based.

After the several parts of the telescope have been put into correct relationship they should be carefully marked so that they can be accurately replaced if for any reason they must be removed. Preferably they should not be disturbed. It is better, for instance, to protect the mirrors by suitable moisture proof and absorbing coverings than to follow the not uncommon practice of removing them from the telescope for storage or transportation. In this respect the modern aluminium or chrome-aluminium coatings are decidedly less liable to damage by exposure than silver, which must be protected most carefully from dew and dampness and be dry before being covered.

II

As much of the remaining work must be done with the telescope in its intended position, some consideration must be given to the selection and preparation of the site.

Usually the site for the amateur's telescope is very much a matter of compromise. He has to make the best of the space available or that diplomacy may achieve. A clear view for some distance eastward and westward (the east darkens first) should be the first consideration, after which is access to the pole.

Any obstruction extending not more than 15° above the (true) horizon may be ignored as seeing is never good below that. An occasional tree or chimney must be put up with but, if possible, during the principal observing months, the prevailing winds should blow the smoke and hot gases from neighbouring chimneys away from the site, which should be high rather than low and screened from house and street lights.

The most satisfactory arrangement, of course, especially in rigorous climates, is some sort of observatory, however humble, in which the telescope can be set up permanently and be ready for use in a few minutes when opportunity for observation offers. Failing an observatory, which need not be expensive,[6] a fence or even a trellis to protect from the wind adds greatly to one's comfort and efficiency.

The site for the portable telescope should be made ready either by

[6]See The Small Observatory and its Design; this JOURNAL, vol. 32, p. 49 ff, 1938.

the well-known centre, plane, groove method or by an arrangement in which the grooved plate is replaced by a second drilled plate as shown at *A*, Fig. 1, for the usual three-footed base and at *B* for a base having four feet.

First, a true (not compass) meridian line is established through the centre of the site. Second, with the meridian line as a guide, the positions for three (or four) posts are laid out so that when the telescope is correctly oriented the points of the levelling screws shall rest centrally on them. When driven firmly into the ground the tops of the posts, which may be 4x4 in. and well tarred for durability, are cut off level with each other and close to the surface.

Three (or four) plates about 4 inches square of No. 12 or 14 B.W.G. iron or brass are provided. Two of the plates have a ⅜-inch

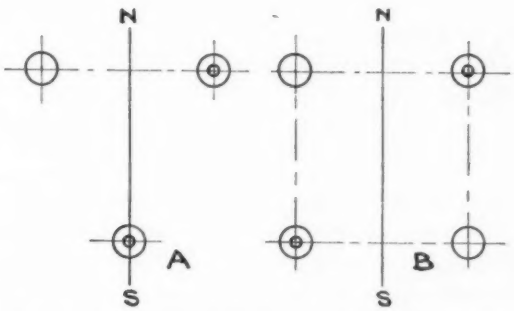

FIG. 1—Preparation of site for a portable telescope, A, for a 3-foot base; B, for a base having 4 feet.

hole drilled centrally to take the pointed ends of the levelling screws, the third is left plain. The plain plate and one drilled plate are secured to two of the posts; the drilled plate to serve as a pivot on which to turn the mounting in azimuth when setting it into the meridian, the plain plate on which to scribe its position as necessary during the process. The second drilled plate is laid on its post and and is secured to it after the mounting is aligned.

The meridian line is established best with an engineer's transit, less well with two plumb lines brought into line with a low northern

or southern star as it crosses the meridian and lastly by means of the telescope itself. The time of transit can be determined from the sidereal time, which may be computed from the mean time by a method given in this JOURNAL for December 1942, page 473.

III

Having prepared the site the instrument is to be set on its foundation as nearly as can be judged in its correct position and carefully levelled before the second and third parts of the adjustment programme are carried out.

The levelling can be done with a machinist's level, by a circular level such as applied to cameras, or by a plumb-bob. The last is best, being free from breakage, more sensitive than the run of commercial levels and easily extemporized.

The steps in the second part of the work, the adjustment of the telescope to its mounting, are:

1. Balance the telescope.
2. Adjust the finder.
3. See that the optical axis of the telescope is at right angles to the declination axis.
4. See that the declination axis is at right angles to the polar axis.

In the third part are the adjustments of the instrument as a whole to the celestial sphere:

5. Adjust the zero of the declination circle.
6. Set the polar axis to the altitude of the pole.
7. Set the polar axis into the plane of the meridian.
8. Adjust the index of the hour circle.

The order of making the last six of these adjustments is to an extent a matter of choice and convenience. Campbell,[7] assuming the correctness of the first four, makes the rest in the order 7, 6, 5, 8, while Loomis[7] makes the last five in the order 7, 5, 8, 3, 4. The order followed here is that of Grubb.

1. *Balance the telescope.* Balance must be attained both in right ascension and in declination. Secure the telescope in its designed

[7]Campbell, Elements of Practical Astronomy, p. 215. Loomis, Practical Astronomy, 7th ed., 1899, vol. I, p. 28.

position in its saddle. Set the declination axis and the telescope horizontal and clamp in right ascension. Adjust the balance weights on the telescope or move it in its saddle until the same pressure will rotate the tube on the declination axis in either direction with equal ease. A light spring balance or, better, a bag of small shot, is useful as a check.

Next, clamp in declination, unclamp in right ascension and see that the polar axis can be rotated with equal ease in either direction. In balancing a "German" mounting a light weight near the outer end of the declination axis is preferable to a heavy one close in.

When the upper bearing of a yoke mounting is of the "horse shoe" form, weights may be needed on the two points. A fork mounting should require little or no balancing in right ascension. Telescopes having "Springfield" and similar forms of stationary eyepiece mountings are commonly balanced in both directions by a single weight carried on a curved or, more logically, an L-shaped, rod extending from the upper part of the tube. The upper portion of the rod should be parallel to the declination axis. Balance in right ascension is attained by moving the balance weight along this part of the rod and in declination by altering the projection of the rod from the end of the telescope tube.[5]

All set screws, bolts and weights must be adequately secured after each adjustment for balance.

2. *Adjust the Finder.* A finder telescope is in correct adjustment when its optical axis is parallel to that of the main telescope. If the finder is of the usual type its optical axis is defined by crosswires which can be placed in the common focus of the objective and the eyepiece. These wires, usually in fact spider web, are mounted in a ring retained in place by pulling screws passing through the wall of the containing tube and tapped radially into the ring. Accordingly the screws must first be loosened on the side *from* which the ring is to be moved before the opposite screws are tightened, otherwise the

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[5]When additional equipment, such as a camera, a solar observing screen or a spectroscope, is attached to the telescope it will probably be necessary to readjust the balance weights. In this connection see G. Van Biesbroeck, "On the balancing of Equatorial Telescopes." *Popular Astronomy*, vol. 50, p. 253, 1942.

ring may be deformed and the wires broken. The screws need not be set up more than hand-tight.

Another form of finder consists simply of a pair of sights, crossed wires for the fore sight and a peep sight for the rear.

The finder is adjusted most conveniently in daylight. First, focus sharply the wires in the finder and set them exactly in the centre of its field. Next, point the main telescope on a small well-defined distant object. Clamp, bring the object to the centre of the field of the highest-power eyepiece and focus sharply. Third, move the finder in its supports until the object is in the centre of the finder field also. When this has been done as closely as possible it may yet be found necessary to perfect the setting by a very slight movement of the wire ring if on moving the eye from side to side of the eyepiece the wires move away from the object. Such movement is an effect of parallax and can be cured by moving the ring.

Finally the tube carrying the wire ring should be rotated until, the telescope being stationary, a star will run along one of the wires in its passage across the finder field.

Unless the wires can be illumined, a simple matter with flash-light bulbs, neither form of finder is of much use except against a light sky or an object having a bright disc. The wires may be rendered visible in the case of a bright star by throwing it slightly out of focus, but for faint stars this is ineffective. Furthermore, unless the finder optically is a small copy of the main telescope, though perhaps of shorter focus, the differing orientation of the two fields is inconvenient.[9] When the telescope is a small reflector of the usual focal length F8, the value of a finder is problematical. An eyepiece of very low power, *e.g.*, 4 or 5 magnification per inch, may prove generally more useful.

In adjusting a telescope much of the work is done by the method of reversal. By rotating the polar axis through 180° or thereabouts, that end of the declination axis which before faced east is caused to face west. The result is that an error due to mis-alignment becomes

[9]The orientation of the field may be found as follows: With the telescope stationary, stars drift westward across its field. The east-to-west direction being thus found, swing the telescope in declination towards the elevated pole. The stars in the field will move towards the opposite pole.

by reversal an error of the same amount but opposite in direction, whence the correct line is the mean of the two.

As ordinarily proportioned, however, unless special provision is made temporarily, a yoke mounting does not permit of reversal in this sense and a different method of reaching the same result becomes necessary.

The important point is that in all correctly adjusted equatorial mountings, irrespective of type, their declination axes will have the same inclination when observing the same object at the same hour angle. In the adjustments which follow it is frequently this inclination that has to be determined.

While diagrams and figures in the text are of use, a model equatorial mounting that can be made in a few minutes will make clear the principles underlying the adjustment of a telescope much more readily. To paraphrase a remark of Airy's, "It is of importance that one who wishes to understand should see for himself that things do happen as I shall attempt to describe."

Make a paper tube, say, ⅜-inch diameter and about 4 inches long to represent the telescope. Bend a piece of cardboard into a flat ⌊⌋-shape with one long and one short leg to represent the body of the mounting. Fasten it to a piece of board to keep it steady. Bend a piece of stiff wire to a right angle with one leg about 1½ inches long and the other about 3 inches long. Push the long leg, representing the polar axis, through the ends of the vertical legs of the mounting and the short leg, representing the declination axis squarely through the paper tube. A 1½-inch disc can be glued onto the polar axis before putting it into the mounting, to serve as an hour circle. The disc can be graduated as follows:

Looking at the upper end of the polar axis with the declination axis to the east or left hand and horizontal, mark the top of the vertical diameter of the disc **24**, the bottom **12**, the east end of the horizontal diameter **6** and the west end **18** to correspond with the march of time across the meridian as the polar axis is turned clockways as seen from this end if it were following a star.

Suppose now a star at the intersection of the equator and the meridian be observed with the telescope east of the polar axis. When the telescope is at right angles to the declination axis, the declination

axis will be horizontal and the hour circle will read **24**. After reversing the telescope to the west side of the polar axis and again sighting the star, the declination axis again will be horizontal and the hour circle will read **12**, the polar axis having been turned through 180° or 12 hours. This condition is shown in Fig. 2A, where we are looking from the direction of the pole down the polar axis, of which *P* is the upper end, *H* is the hour circle in the plane of the paper, *PD* the declination axis, *EM* the telescope before reversal, *M* being the mirror end, and *PD'* and *E'M'* these parts after reversal.

Now remove the model telescope and set it back onto the declination axis so that the angle *MDP*, the "test" angle, between the lower end of the telescope (mirror end if it is a reflector, eye end if a refrac-

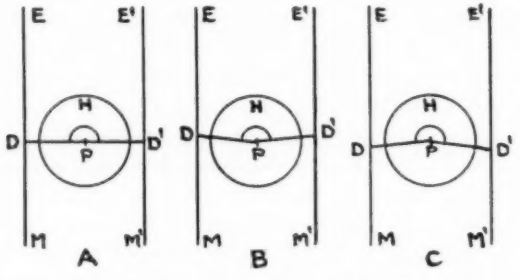

FIG. 2.—To explain how to adjust the telescope.

tor) is greater than a right angle. This condition is shown in Fig. 2C. How will this error affect the position of the declination axis and the hour circle readings when the telescope is pointed to the star?

Before the telescope can be brought to bear it will be found necessary to rotate the polar axis through a small angle eastwards from its previous meridian position. The declination axis will now be inclined downward toward the east and that, in consequence, the **24** h. mark on the lower circle will be to the eastward of its previous position and the pointer consequently will indicate less than 24 hours Similarly, when reversing the telescope the polar axis must be rotated westward through the above small angle to bring it back to **24**, then through 180° to **12**, then through a further small angle westward before the telescope can be reset on the star. Thus the whole angle

turned through in this condition is more than 180° and the hour circle will read more than 12 h.

If the test angle be less than a right angle, as in Fig. 2B, the declination axis will slope upwards towards the telescope on both sides of the polar axis instead of downwards as in the preceding example, and the total angle turned through in reversing will be less than 180°.

If now the model telescope be restored to perpendicularity with the declination axis the effect of similar errors in the angle between the declination and polar axes can be shown by directing the telescope to the pole instead of to the equator.

Finally, it will be noted that as the positions of the telescope during these two sets of experiments are at right angles to one another any small error remaining after correcting the one cannot appreciably affect the other adjustment.

Summarizing the indications of error given by these tests, we have in both adjustments Nos. 3 and 4:

Angle	correct	. . . . . rotation of polar axis	$= 180°$
"	too large	. . . . . " " "	$> 180°$
"	too small	. . . . . " " "	$> 180°$

In a yoke or fork mounting it is necessary to define how the test angle is to be measured since unless correct it will be obtuse referred to one arm but acute relative to the other. The dilemma can be solved as follows:

Let the telescope be directed to a point near to the intersection of the meridian and the equator. Then, the declination axis being approximately horizontal, that arm of the yoke or fork lying to the east of the telescope corresponds to the position of the telescope itself when east of the polar axis of a "German" mounting. That arm then can be marked "east" or otherwise identified and this position can be described as "telescope east."

It may be noted here that while in a "German" mounting a defect in adjustment No. 3 usually can be corrected with little trouble, an error in No. 4 is a much more serious matter, and that the difficulty of correction is great in the case of both these adjustments when the mounting is a yoke or fork. It is then of importance that the ac-

curacy of the work at both these points be proved before the instrument be allowed to leave the workshop.

The adjustment of a "German" mounting is discussed first, then the modifications needed for proving a yoke or fork.

No. 3. *See that the optical axis of the telescope is at right angles to the declination axis.*

As an actual star does not stand still during the test, its movement must be allowed for. A driving clock is not needed.

Select an easily recognizable star near to the equator and at a time when its eastern hour angle is small. With telescope east, clamp in declination and bring the star to the centre of the field of the highest-power eyepiece. Now with watch in hand (civil time will serve) move the telescope westward until the star is out of the field. Letting the telescope remain stationary, note the time by the watch at the instant when the star crosses the centre of the field and read the hour circle, estimating fractions of a division as closely as possible, say, to the tenth. Move the telescope slightly westward again, repeating the process some 5 times, noting the time and the hour circle reading when the star is in the centre of the field. Now reverse the telescope, clamp in declination, bring the star to the centre of the field again, and take a similar series of observations.

There are now to be compared the intervals of time between the direct and reversed readings as shown by the watch and by the hour circle, respectively, compensating the latter for the reversal by adding 12 hours. If these intervals be equal, the polar axis has been turned through 180° and the test angle between the lower end of the telescope tube and the declination axis is a right angle. If the hour circle interval is the greater then that angle, as will have been seen from the experiments with the model, is too large. If that interval is the smaller, that angle is too small.

In determining these intervals, instead of taking the averages of the columns and comparing them, it is safer to obtain individual intervals between pairs of direct and reversed readings and to use the averages of these individual differences to find the final differences to be compared, as in that way discrepant readings are more easily discovered and discarded.

Suppose, for example, these final differences are:

By watch . . . . . 10^m38^{s10}

By hour circle . . . . . 12 58 ;

evidently the telescope has been turned through an angle greater than 180°. In a "German" mounting this can be corrected by putting a shim under the upper end of the saddle. If L be the length, say 12 inches, between the centres of the telescope supports; S, the difference of time in seconds, here 107; T, the thickness of the required shim, will be, since 1 second of time=15 seconds of arc:

$$T=\frac{15SL}{206{,}000} \text{ in., or, in this case, } \frac{15\times107\times12}{206{,}000}=0.094 \text{ in.}$$

No. 4. *See that the declination axis is at right angles to the polar axis.* Except that a star close to the pole instead of to the equator is used, the procedure and interpretation of the observations are the same as for No. 3.

In a yoke mounting the method of reversal used in the adjustment of a "German" mounting being inapplicable, reversal must be accomplished in another way such as is now to be described.

Nos. 3 and 4. It is convenient to make these adjustments in reverse order, completing No. 4, to see that the declination axis is at right angles to the polar axis, before the telescope is mounted in the yoke. As the polar axis is defined by the line through the respective centres about which the upper and lower bearings of the yoke rotate this test resolves itself into proving that the axis of the trunnion bearings in the arms of the yoke is at right angles to the axis of rotation of the yoke.

Procure a tube of the same diameter as the trunnions and somewhat longer than the overall width of the yoke. Fit it with peep and crossed wire sights as described above. Set the tube in the trunnion bearings and prove that the sights define its axis by rotating the tube, marking where the lines of sight strike a screen placed some few feet away. Bring the tube to the horizontal, sight the screen, marking the point of sight on the screen. Reverse the sighting tube end for

[10]Strictly, as sidereal time gains nearly 10 sec. per hour on mean time, the watch interval should be increased in that proportion. In this instance the thickness of the shim would be decreased by about 2 per cent. by this correction.

end in the bearings and rotate the yoke until the tube is again horizontal. Re-sight and mark where the second line of sight strikes the screen.

If the two marks coincide or do so as the yoke is rotated slightly in its bearings the axis of the declination trunnion bearings is at right angles to the axis of rotation of the yoke and the telescope can be mounted with its trunnions in the bearings. If not, the higher trunnion bearing must be moved down towards the lower end of the yoke until, as proved by this test, the two lines of sight coincide. If the position of this bearing is changed by enlarging its bore the space above the trunnion should be filled with white metal, plastic wood, smooth on cement or other suitable material.

The inversion of the yoke required in this test is a simple matter with small telescopes as with care the yoke can be lifted from the base, inverted and replaced in its bearings without the base being moved. With larger and heavier yokes having a "horse shoe" form of upper bearing it may be necessary or more convenient to fit into the gap in the horseshoe a temporary section of correct radius for use while inverting the yoke.

No. 3. *To see that the optical axis of the telescope is at right angles to the declination axis.* The telescope having been mounted on its trunnions in the yoke, place the mounting at right angles to a distant screen or wall. Tilt the mounting bodily on the east and west legs until the yoke is horizontal[11] and secure it on steady blocking. Block up under the raised leg also, to prevent the mounting from falling back into its normal position. With the telescope tube set horizontally and at an hour angle of 6h., focus the screen sharply and mark on it the point of sight. Rotate the telescope 180° to the opposite 6h. angle and again mark the point of sight on the screen. If the two marks coincide, or do so as the telescope is moved slightly in declination, the declination axis and the optical axis of the telescope are at right angles. If they do not, the error must be corrected by readjusting the positions of the trunnion supports on the telescope tube until the two marks coincide.

[11]It is not necessary that the instrument be placed precisely in the positions specified. Distance from the screen must permit of its surface being brought into sharp focus of the eyepiece used during the test.

(*To be continued*)

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

How Many Amateur Reflectors?

From A.G.I.'s page bearing the heading "Telescoptics" in February 1943 *Scientific American:*

This department often is asked for the "inside figures" on the total number of telescopes made since "Amateur Telescope Making" first appeared in 1926. We don't know. To obtain really solid data on this would be difficult. All we can do, therefore, is "guestimate". Over 30,000 copies of "A.T.M." have been purchased since 1926, but what percentage of purchasers actually made telescopes? What percentage made two? Three? Five? Ten? (Yes, some have made that many). Our guestimate is 20,000 telescopes—what's yours? Some think this figure too conservative. Perhaps. Perhaps not. Anyway, let's say 20,000.

It 's fun to imagine all these 20,000 telescopes assembled in one place. Let's allot each one ten feet square and one observer. That represents a Telescope Farm of about 50 acres, solid. Go aloft in a plane and look down at them all!

To make it more interesting, let's have them all pointed at one object; it might as well be the plane, and there'd be a poetic justice in having in the plane the man who, more than any other man, made it all possible—Russell Porter. Maybe he'll wave a hand over the side (this story is becoming melodramatic).

Of course, not all these telescopes are now in actual use. There must be a few thousands which could be put in other hands to good advantage. Readers also ask us, now and then, where they can purchase a second hand telescope. To test whether any good could be done by thawing out this frozen situation we shall be glad to publish, in one number, the names and addresses of those who have second hand telescopes they would be willing to dispose of.

C. A. C.

The Mysterious "Planet" in the System of 61 Cygni

In Notes and Queries in the December issue a brief reference was made to an object in Cygnus newly discovered by K. Aa. Strand and announced at a meeting of the American Philosophical Society in Philadelphia. This was given wide publicity in the newspapers and many inquiries were made regarding it. In a personal letter Dr. S. A. Mitchell gives some information regarding the reported "planet" and also about another interesting object in Ophiuchus discovered photographically at the Leander McCormick Observatory. We take the liberty of printing the letter herewith:

We here at the McCormick Observatory were quite puzzled as you are by the use of the term "planet" to apply to a body in the system of 61 Cygni. We have not seen the paper but correspondence with H. N. Russell, who heard Strand present the paper, tells me that the word planet was used merely to represent a very small disturbing body.

You will be interested in a body discovered through McCormick photographs by the use of an objective grating, the paper by Reuyl and Holmberg to appear in the January *Astrophysical Journal*. The small object, which is of lesser mass than Strand's planet, we have however not called a planet. It is the long expected third body in the system of 70 Ophiuchi, now firmly established with a period of 17 years.

Again for me to quote Russell, he believes these two objects of very small masses, discovered by visual refractors through photography with an objective grating, are of the utmost importance to the subject of astronomy.

C. A. C.

THE 400TH ANNIVERSARY OF THE DEATH OF COPERNICUS

On May 24, 1943, appropriate tribute will be paid to the founder of modern astronomy, the great Copernicus, marking the 400th anniversary of his death. The initiative in this matter has been taken by the Kosciuszko Foundation, with headquarters at 149 East 67th Street, New York, N.Y., which has published a monograph of 88 pages, 7 by 10 inches in size, filled with authoritative facts and adorned with numerous reproductions of rare portraits and historic scenes. A special edition well bound may be obtained for $2.50; while a popular edition paper bound, but with the same beautiful coloured cover design, is obtainable at 75 cents a copy.

Copernicus (in Polish, Kopernik) was born at Thorn on the Vistula river, not very far from the Baltic sea, on February 19, 1473, and on the 400th anniversary of that event a new edition of his epoch-making work, *De Revolutionibus Orbium Coelestium*, was published. In recent years the proposal has been made to publish a scholarly edition in English. The present is surely a good time to plan for this. Perhaps it also may bear the imprint of Thorn! In the meantime the valuable publication mentioned above is recommended to the many friends of Poland and of astronomy.

C. A. C.

MEETINGS OF THE SOCIETY

AT TORONTO

November 10, 1942.—The Society met at the usual place and hour, Dr. D. W. Best in the chair.

One candidate was duly elected to membership in the Society, viz:

Dr. Norman M. Wrong, 170 St. George Street, Toronto.

Mr. J. H. Horning then gave an address on "The Solar System." He briefly covered the main characteristics of the sun, planets, satellites, comets and meteors, referring especially to some of the more recent information about sunspots and solar activity, the sun's rotation and atmosphere, methods of determining distances within the solar system, and the physical characteristics of the various members.

Before the meeting blank slips were distributed to the members and visitors who were invited to submit in writing points on which further information was desired. Many questions were posed as a result and the speaker and others briefly answered most of them. A few needing more lengthy information were set aside for answer by Dr. F. Shirley Jones in her talks on "Spectroscopy."

Miss E. M. Fuller presented the short book review, dealing with Sverre Petterssen's "Introduction to Meteorology." The book, involving a minimum of higher mathematics, was intended as a background for the study of modern weather science. "It is intended more to stimulate the student's interest rather than for use as a technical treatise," she said.

Dr. F. Shirley Jones then gave the third in the series of short lectures on "Spectroscopy." She dealt with the information revealed to the astrophysicist by the spectra of celestial objects and the members of the solar system.

The peak intensity of light and appearance of lines in stellar spectra gave information on the star's temperature, she said. Dark lines in spectra indicated that gases in the star's reversing layer absorbed some of the light from the photosphere, and in turn gave out radiation of their own. The 62 elements found in the sun's spectra occur in approximately the same proportion as the same elements are found in the earth's crust and atmosphere. The Doppler effect indicated in the solar spectrum showed that the sun did not rotate as a solid body but that the rotation was greater at the solar equator than at the poles.

Study of the spectra of light reflected by the planets indicated many interesting facts about their atmospheres, Dr. Jones pointed out. Venus, it appears, may have an atmosphere of formaldehyde with carbon dioxide in the outer regions. Mars' atmosphere reveals much less water vapour than the earth's, and less than one-tenth of one per cent. of the oxygen in the earth's atmosphere. The polar caps may consist of a mixture of ice and ammonia. Jupiter's atmosphere, too cold to hold water vapour, apparently consists of ammonia and methane; the ammonia possibly existing in fine crystal form in the clouds. Saturn probably

has a similar atmosphere but much of the ammonia is likely frozen out. Uranus and Neptune indicate the existence of atmospheres of methane with all the ammonia frozen out. Spectra of comets appear to undergo changes with the object's distance from the sun, similar to the changes observed in the appearance of the comets, the speaker said.

FREDERIC L. TROYER, *Recorder.*

November 24, 1942.—The Society met in the McLennan Laboratory University of Toronto, at 8.00 p.m., Dr. D. W. Best in the chair.

Miss Ruth J. Northcott presented the main paper of the evening on the subject: "What's New about Jupiter?" After dealing with the history of the planet, the discovery of its retrograde motion, Galileo's first view of its four largest moons and their motions, and the later discovery of seven other satellites, Miss Northcott described how the Galilean satellites made possible the first determinations of the speed of light.

The speaker particularly dealt with the atmosphere of Jupiter. Most of the markings show continual change, which indicates they are possibly cloud formations, but some stay for weeks and thus have been of value in determining Jupiter's speed of rotation. Wildt's thoretical considerations of the internal constitution of the planet were discussed in some detail, and some of the problems still to be solved were suggested. This part of the lecture appears in greater detail in the present number of this JOURNAL.

Dr. F. Shirley Jones then presented the fourth paper in the short course on "Spectroscopy." She outlined characteristics of the various spectral classes and went on to describe how their study can bring the astronomer much information about the stars and galaxies. The spectroscope tells us a lot more about the stars than their chemical composition. Each line tells us whether the light comes from an excited or a neutral atom. The study of the lines gives us information on the distances of objects beyond the point where they can be determined by parallax, and the displacement of the lines indicates whether the body is moving towards us or away from us; the shapes of the lines show whether the star is rotating. Radial velocities of 10,000 stars have been determined by the spectroscopic method. In some stars there is an indication that the star is throwing off a shell, while in others a turbulence or boiling surface is revealed. Dr. Jones also briefly outlined the temperature sequence, absolute magnitude effects and the relationship of spectra and luminosity.

A committee to nominate the officers for the Toronto Centre for 1943 was then appointed on motion of Miss Northcott, seconded by Mr. C. A. Crook. The committee, to consist of Messrs. J. R. Collins, T. H. Mason, S. C. Brown, H. G. Duncalfe and E. J. A. Kennedy, was instructed to bring in their recommendations at the annual meeting on December 8.

FREDERIC L. TROYER, *Recorder.*

December 8, 1942.—The Society met at the usual place and hour, Dr. D. W. Best in the chair.

Four persons were duly elected to membership in the Society, viz:

Mr. William G. Elliott, 19 Belsize Drive, Toronto.
Mr. John G. DelGrande, 47 Gloucester Street, Toronto.
Mr. Sidney V. Soanes, 64 Airdrie Road, Leaside, Ont.
Mr. Herbert A. Knowles, P.O. Box 511, Toronto.

Dr. C. A. Chant addressed the Society on "Isaac Newton—His Three Hundredth Anniversary." He dealt with the life and work of the great English scientist who was born on Christmas Day in 1642, and referred to interesting events in Newton's life as a student, his discovery of the law of universal gravitation, of the composition of light, and of the method of Fluxions or the Differential Calculus. He also mentioned his experiments in chemistry, his studies in theology and chronology, his relation to the Revolution of 1690 and his work as Warden and Master of the Mint. (Dr. Chant's address is published in full in the Society's JOURNAL, issue of January 1943.)

Miss E. M. Fuller then presented the short book review, dealing with "Essentials of Astronomy" by Prof. J. C. Duncan of Wellesley College.

Dr. F. Shirley Jones concluded the series of five short talks on "Spectroscopy" with a description of some of the more unusual types of astronomical spectra and the information revealed by them to the astronomer. "The stars as a whole tell us a detailed story of themselves in their light, but in the story we get from some other celestial objects the words seem to be garbled," she said.

The lines in the spectra of many of these objects are indistinct and difficult to interpret, Dr. Jones pointed out. The wide bright bands in the spectra of novae indicate the star is giving off an expanding shell. The spectra of planetary nebulae, such as the Ring Nebula in Lyra, is altogether different from that of novae. An extremely low pressure is revealed by the light of the ring or envelope, and the atoms exist in an extreme state of ionization. Similar lines to those in the spectra of planetary nebulae are found in the light record of the diffuse bright nebulae such as the Great Orion Nebula. Another type is the absorption-line nebulae, e.g., the Pleiades, where the exciting stars are surrounded by cooler matter. Dr. Jones went on to describe the spectra of the external galaxies which show the *H* and *K* lines of calcium in fairly normal position in the nearer objects with an increasing shift of the lines to the red end of the spectrum in the more distant galaxies.

The Chairman announced that the annual business meeting and election of officers would follow immediately after the regular meeting which was then adjourned.

FREDERIC L. TROYER, *Recorder.*

AT MONTREAL

October 22, 1942.—The Montreal Centre of the Royal Astronomical Society of Canada held its twenty-fourth annual meeting and election of officers on the above date in the Macdonald Physics Building, McGill University. Reports of the year's activities were read, including a report of the weekly observation

meetings held throughout the summer months at the Ville Marie Observatory where the Centre's six-inch refractor telescope is mounted.

Dr. R. Meldrum Stewart, Dominion Astronomer, Ottawa, was the speaker of the evening. In his opening remarks Dr. Stewart commended the Centre on its progress since his last visit in December 1937. Speaking on the subject "Life in the Universe," Dr. Stewart discussed first the conditions necessary to support life and the possibility of life in other parts of our solar system. Although the planet Mars may have supported human or animal life millions of years ago, and conditions on Venus may be suitable for life millions of years hence, it has been proven, both theoretically and by practical experiment, that animal life does not exist in any part of the solar system except on the earth. Dr. Stewart then spoke on the possibility of the existence of other solar systems similar to our own. Working on the theory, generally accepted by astronomers to-day, that our solar system was formed by the collision of a star with a binary star companion of our sun, the binary companion thus splitting up to form the planets, it has been computed that of the probable five hundred star collisions in the Milky Way since its origin, only one in five would involve binary stars. Each collision with a binary might not satisfy the very rigorous conditions necessary to form a solar system, however, and thus it has been computed that in our galaxy perhaps one such system exists—our own. In conclusion Dr. Stewart stated that as the number of spiral nebulae has been estimated at one hundred million, one hundred million planetary systems may exist. Not all of these would have planets suitable to support life and although further computation reduces the number to one million planets, it is still very probable that life, and intelligent life, does exist in other parts of the universe.

An interesting discussion followed the address, and the chairman, Mr D. P. Gillmor, in thanking Dr. Stewart, compared his presence to answer the members' questions to an inexhaustible bank account.

The members elected to office for year 1942-43 were as follows:—*Honorary President*—Mgr. C. P. Choquette; *President*—D. P. Gillmor, K.C.; *Vice-President*—G. Harper Hall; *Secretary*—Henry F. Hall; Treasurer—F. J. De Kinder; *Recording Secretary*—Miss I. K. Williamson; *Members of the Council*—A. M. Donnelly, J. W. Duffie, O. A. Ferrier, DeLisle Garneau, J. E. Guimont, G. R. Lighthall, F. P. Morgan, E. R. Paterson, Dr. W. B. Ross, Dr. A. N. Shaw.

The twelve-inch reflector telescope, recently donated to the Montreal Centre, was on display at the meeting and aroused much interest among the members.

ISABEL K. WILLIAMSON, *Recording Secretary*

November 19, 1942.—The Montreal Centre held its second meeting of the season in the Macdonald Physics Building, McGill University, the president, Mr. D. P. Gillmor, in the chair. Mr. DeLisle Garneau was reappointed chairman of the Telescope Committee and it was announced that observation meetings would be held on Saturday evenings from 7.30 to 9.30, when members of the Telescope Committee would be in attendance at the Ville Marie Observatory.

The speaker of the evening, Mr. Frederick Mahaffy, M.A., Meteorologist, Montreal Airport, had chosen as his subject, "Twenty-five Years Progress in Meteorological Science," because this period is marked by a number of important developments which meteorologists hope are at least a start towards tracing some of the involved systems which make up our atmosphere.

Twenty-five years ago, Mr. Mahaffy said, the weather forecaster received surface observations once or twice a day from a limited number of observing stations. Then observations were plotted on the usual weather map from which the forecaster made his deductions. Attempts were made to forecast the movement of rain areas but this was attacking the symptoms instead of the disease. The forecaster faced another obstacle for his only observations were those made on the earth's surface. It was the recognition of these limitations which determined the course of a great deal of the research over the past twenty-five years.

In the early 1920's the two brilliant Norwegian meteorologists, V. Bjerknes and his son, J. Bjerknes, developed the theory of "fronts" and "air-masses" which is probably the most noteworthy advance which the science of meteorology has made in a century. Mr. Mahaffy then proceeded to explain this theory—how the atmosphere tends to assume the properties of the surface over which it passes, and classifying the air-masses as polar continental, polar maritime, tropical maritime and tropical continental. The sharp boundary between two air-masses where temperature, moisture-content and other properties change is known as a front. The forecaster of to-day is concerned very largely with locating these fronts and tracing their motion. It is next necessary to determine their characteristics and calculate the speed and direction in which they are moving. It is also necessary to know something about the upper atmosphere, and Mr. Mahaffy spoke of the various methods used to make observations at high levels. The radiosondes in use to-day have the advantages of recording observations automatically in any kind of weather and of attaining heights of from sixty to seventy thousand feet.

Mr. Mahaffy, after explaining how the meteorologist makes use of the observations thus obtained, turned to the more practical side of the subject and spoke of the extent to which meteorology depends upon communication. Meteorologists use every type available—telegraph, teletype, radio and cable—and with the recent development in aviation it became necessary for the Meteorological Services to have their own communication systems. The teletype system in Canada alone includes some several thousand miles of lines used solely for meteorological traffic and the extent of the system in the United States is almost ten times as large.

Aside from changes in communications in the last few years there has also been a very large increase in the forecasting facilities. Ten years ago all forecasting in Canada was done from one central office in Toronto. Now there are ten such forecasting centres fully staffed with trained meteorologists.

Mr. Mahaffy illustrated his lecture with a number of slides of charts and maps. The discussion which followed the address showed the keen interest of

the members. Mr. Evans thanked the speaker on behalf of those present. (The address will be printed in a later number of this JOURNAL.)

ISABEL K. WILLIAMSON, *Recording Secretary.*

December 10, 1942.—Open Meeting.—A series of astronomical films entitled "The Universe as Seen through the Largest Telescopes" filled to capacity the lecture hall of the Macdonald Physics Building, McGill University, on the above date. The meeting was open to the public and it was estimated that about 240 members and visitors were present, while over a hundred had to be turned away at the doors.

The series, taken through the telescopes at the Mount Wilson, the Yerkes, and the Lowell Observatories, included "The Eclipse of the Sun," which showed some excellent scenes of the sun's corona and prominences; "Going to the Moon," with close-ups of the moon's seas, craters and mountain ranges; "The Solar System," showing the movement and aspects of the planets and comets; and "The Milky Way" with its incredible number of stars and nebulae.

The president, Mr. D. P. Gillmor, in welcoming the visitors, expressed the hope that the meeting would stimulate their interest in astronomy and that many would become members of the Society. He announced a series of popular lectures to begin early in January which would be of particular benefit to new members. At the close of the meeting over twenty persons applied for membership in the Society.

January 11, 1943.—Second Open Meeting.—Because the lecture hall in the Macdonald Physics Building had not been large enough to accommodate the crowd which came to the open meeting on 10th December, the Montreal Centre arranged a second evening of astronomical films in Moyse Hall, McGill University, on January 11th, 1943.

The films shown on this occasion were not the same as those shown at the previous meeting. A sound track, supplying a running commentary, added greatly to the interest of four films entitled "The Moon," "The Weather," "The Solar System" and "Exploring the Universe," which were well received by an audience of over two hundred visitors and members. The success of the evening was evidenced by the fact that over twenty of the visitors applied for membership in the Society.

ISABEL K. WILLIAMSON, *Recording Secretary.*

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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA
1890-1942

The Society was incorporated in 1890 under the name of The Astronomical and Physical Society of Toronto, and assumed its present name in 1903.

For many years the Toronto organization existed alone, but now the Society is national in extent, having active Centres in Montreal and Quebec, P.Q.; Ottawa, Toronto, Hamilton and London, Ontario.; Winnipeg, Man.; Edmonton, Alta.; Vancouver and Victoria, B.C. As well as about 700 members of these Canadian Centres, there are over 200 members not attached to any Centre, mostly resident in other nations, while some 300 additional institutions or persons are on the regular mailing list for our publications.

The Society publishes a monthly JOURNAL containing about 500 pages and a yearly OBSERVER'S HANDBOOK of 80 pages. Single copies of the JOURNAL or HANDBOOK are 25 cents, postpaid. In quantities of 10 or more copies, the price is 20 cents a copy.

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